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**Atmospheric and
Environmental Research, Inc.**

**Determining the Ocean's Role on the Variable
Gravity Field and Earth Rotation**

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FINAL REPORT

Our 3-year investigation, carried out over the period November 19, 1997–November 18, 2000, focused on the study of the variability in ocean angular momentum and mass signals and their relation to the Earth's variable rotation and gravity field. This final report includes a summary description of our work and a list of related publications and presentations.

One thrust of the investigation was to determine and interpret the changes in the ocean mass field, as they impact on the variable gravity field and Earth rotation. In this regard, the seasonal cycle in local vertically-integrated ocean mass was analyzed using two ocean models of different complexity: the simple constant-density, coarse resolution model of Ponte (1997, *Geophys. J. Int.*, 130, p. 469) and the fully stratified, eddy-resolving model of Semtner and Chervin (1992, *J. Geophys. Res.*, 97, p. 5493). The dynamics and thermodynamics of the seasonal variability in ocean mass were examined in detail, as well as the methodologies to calculate those changes under different model formulations. Results were discussed at length in Ponte (1999) (see list of publications at the end of this report).

Another thrust of the investigation was to examine signals in ocean angular momentum (OAM) in relation to Earth rotation changes. A number of efforts were undertaken in this regard. In collaboration with Jolanta Nastula from the Polish Academy of Sciences, results from several runs of the constant density model previously mentioned were used to analyze in detail the effects of OAM on the excitation of polar motion, at seasonal and shorter time scales. Sensitivity of the oceanic excitation to different assumptions about how the ocean is forced and how it dissipates its energy was explored. Comparisons with the oceanic excitation series calculated from the more advanced MIT ocean model, described by Ponte et al. (1998, *Nature*, 391, p. 476), were also carried out. The results were summarized in a paper by Nastula and Ponte (1999).

A major effort was dedicated to analyzing results from 11+ years of output from the MIT model, which had served as the basis for demonstrating the role of the ocean in driving polar motion (Ponte et al., 1998). Detailed analysis were carried out of both the equatorial components of OAM, related to polar motion, and the axial component of OAM, related to length-of-day (LOD) variations. Relation of OAM variability to regional changes in oceanic currents and mass field and to the Earth rotation parameters was addressed in detail. The analyses of OAM in the MIT model were written up in two different papers (Ponte and Stammer, 1999, 2000), highlighting the importance of oceanic excitation in explaining the annual and Chandler wobbles, and demonstrating the presence of measurable oceanic signals in LOD.

Besides using OAM calculations from forward model runs without any data constraints, substantial effort was dedicated to use the MIT ocean model and its adjoint to estimate OAM values by constraining the model to available oceanic data (altime-

try, monthly hydrography, sea surface temperature). The optimization procedure yielded substantial changes in OAM, related to adjustments in both motion and mass fields, as well as in the wind stress torques acting on the ocean. Constrained OAM values were found to yield noticeable improvements in the agreement with the observed Earth rotation parameters, particularly at the seasonal timescale. The comparison with Earth rotation measurements provides a stringent independent consistency check on the estimated ocean state and underlines the importance of ocean state estimation for quantitative studies of the variable large-scale oceanic mass and circulation fields, including those on OAM. Results are fully discussed in Ponte et al. (2000).

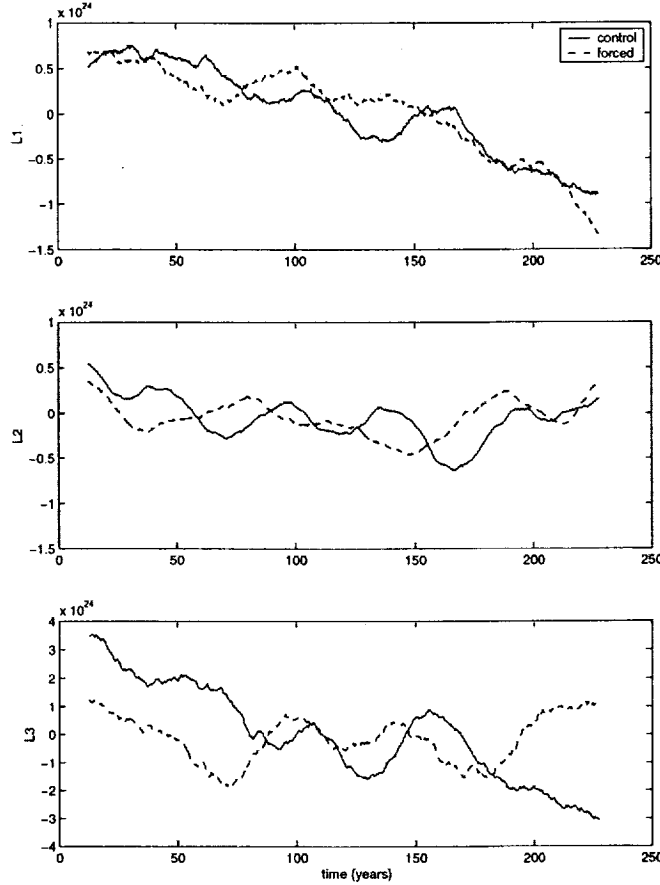


Fig. 1. Time series of OAM ($\text{kg m}^2/\text{s}$): equatorial component about Greenwich meridian (top); equatorial component about 90°E ; axial component (bottom). Original 3-month averaged time series have been smoothed with a moving average window of 25 years. Control run (with no greenhouse forcing) is given in solid, climate forced case in dashed.

The last major activity of the project involved the calculation, analysis, and interpretation of OAM signals in the Hadley Centre (United Kingdom) climate model output provided to us by Jonathan Gregory. Time series of about 240 years of OAM data from suitable control and climate runs (Figure 1) have been analyzed in detail.

Results show that climate change, as modeled under the currently projected scenarios for increased greenhouse forcing, should lead to substantially different trends in the axial OAM component, but not for the two equatorial components (Figure 1). Changes at other time scales (e.g. seasonal cycle) predicted under climate change scenarios were found to be insignificant. Analysis relating these OAM series to possible low frequency signals in Earth rotation have begun. These analyses will continue under other projects and a publication summarizing our findings will be pursued in the months ahead.

For a full description of our major results, please consult the referenced papers. Besides the listed publications, results of our investigation were also the subject of many presentations at several meetings, including those sponsored by AGU and EGS. A list of presentations supported by the project is also provided below.

List of Publications

- Ponte, R.M., 1999. A preliminary model study of the large-scale seasonal cycle in bottom pressure over the global ocean, *Journal of Geophysical Research*, 104, 1289–1300.
- Nastula, J., and R.M. Ponte, 1999. Further evidence for oceanic excitation of polar motion, *Geophysical Journal International*, 139, 123–130.
- Ponte, R.M., and D. Stammer, 1999. Role of ocean currents and bottom pressure variability on seasonal polar motion, *Journal of Geophysical Research*, 104, 23393–23409.
- Ponte, R.M., and D. Stammer, 2000. Global and regional axial ocean angular momentum signals and length-of-day variations (1985–1996), *Journal of Geophysical Research*, 105, 17,161–17,171.
- Ponte, R.M., D. Stammer, and C. Wunsch, 2000. Improving ocean angular momentum estimates using a model constrained by data, *Geophysical Research Letters*, submitted (available by anonymous ftp at ftp.aer.com; cd ponte/stammer/oamc/).

Conference Presentations

- Ponte, R.M., 1998. Understanding the ocean's role on the variable Earth rotation. EGS General Assembly, Nice, April 1998 (*invited*).
- Nastula, J., R.M. Ponte, and D.A. Salstein, 1998. Combined oceanic and atmospheric excitation of polar motion for the period 1993–1995. EGS General Assembly, Nice, April 1998.
- Ponte, R.M., 1998. A preliminary model study of the large-scale seasonal cycle in bottom pressure over the global ocean. WOCE Conference on ocean circulation and climate, Halifax, May 1998.
- Ponte, R.M., and D. Stammer, 1998. Importance of oceanic excitation of polar motion at seasonal and shorter periods. AGU Fall Meeting, San Francisco, December 1998.
- Nastula, J., R.M. Ponte, and D.A. Salstein, 1998. Oceanic impact on polar motion. AGU Fall Meeting, San Francisco, December 1998.

- Ponte, R.M., and D. Stammer, 1999. Regional signals in ocean currents and bottom pressure, in relation to the Earth's angular momentum. AGU Spring Meeting, Boston, June 1999, (*invited*).
- Salstein, D.A., R.M. Ponte, R.D. Rosen and D. Stammer, 1999. Assessing the planetary angular momentum budget with atmospheric upper air and ocean model data. XXII IUGG General Assembly, Birmingham, England, July 1999 (*invited*).
- Ponte, R.M., D. Stammer, and C. Wunsch, 2000. Estimating ocean angular momentum using a general circulation model constrained by data. EGS General Assembly, Nice, April 2000 (*invited*).

REPORT DOCUMENTATION PAGE

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13. ABSTRACT (Maximum 200 words) A number of ocean models of different complexity have been used to study changes in the oceanic angular momentum (OAM) and mass fields and their relation to the variable Earth rotation and gravity field. Time scales examined range from seasonal to a few days. Results point to the importance of oceanic signals in driving polar motion, in particular the Chandler and annual wobbles. Results also show that oceanic signals have a measurable impact on length-of-day variations. Various circulation features and associated mass signals, including the North Pacific subtropical gyre, the equatorial currents, and the Antarctic Circumpolar Current play a significant role in oceanic angular momentum variability. The impact on OAM values of an optimization procedure that uses available data to constrain ocean model results was also tested for the first time. The optimization procedure yielded substantial changes in OAM, related to adjustments in both motion and mass fields, as well as in the wind stress torques acting on the ocean. Constrained OAM values were found to yield noticeable improvements in the agreement with the observed Earth rotation parameters, particularly at the seasonal timescale.				
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